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A Comprehensive Review on Intelligence Control for Complex System

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Abstract— *Control system intellectualization issues are observed. The need for intellectualization of a diverse variety of systems and control approaches is supported. The hierarchy of intellectual control levels is examined, and various artificial intelligence methods are compared. Intelligence control for complex systems involves using advanced algorithms and techniques, such as artificial intelligence and machine learning, to effectively manage and manipulate complex systems. This includes creating models and simulations to understand the system's behavior, sensing and acquiring real-time data, preprocessing and analyzing the data, making decisions based on the analyzed data and system models, adapting control strategies in real-time, facilitating human-machine interaction, monitoring performance, and optimizing control strategies. The goal is to improve efficiency, safety, reliability, and overall performance of complex systems in various domains.*

I. INTRODUCTION

Artificial intelligence (AI) evolved and developed along with the idea of automatic control, beginning around the 1950s, with the first major applications in computing and information science, and later in automated control [1].The first commercial and industrial applications of AI can be traced back to the 1980s [2]. AI has attained a certain level of stability and maturity throughout this time. The significant development in computer technology's capabilities, including hardware implementation of logical and other AI means, is a key aspect that can lead to a reassessment of today's successes and new ups of AI theory and practice. The phrase "intellectual control system" refers to any combination of hardware and software that is linked by a general information process and capable of synthesizing the control objective and finding rational solutions to attain the control goal (in the presence of motivation and knowledge includes environmental and internal status information) [1,3]. Human-machine interaction now enables the capacity to synthesize the control goal, and autonomous control systems capable only of finding reasonable solutions to fulfill the control goal are referred to as "intelligent control systems."Currently, the science and practice of control are very interested in the integration of traditional automatic control methods with AI approaches, as well as AI applications in the field of control for complicated weakly structured objects and processes. Especially when the information, system state, control criteria, and control goals vary over time and become hazy and occasionally contradictory. The report considers a hierarchy of levels of intellectual control as well as a comparative analysis of various AI methods. Because there has been a significant increase in the number of theoretical and applied research in the field of fuzzy controllers over the last decade, the main objective of the study is to examine the important achievements in this area. Unfortunately, even this field does not allow for a thorough review free of the writers' preferences.

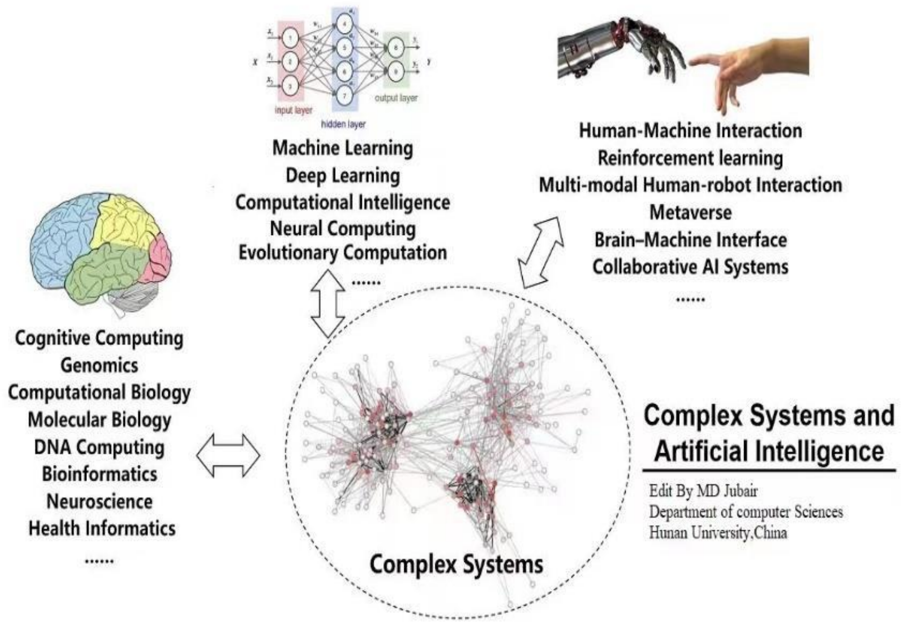

Fig 1: Complex System

Intelligence control for complex systems refers to the ability to effectively manage and manipulate a complex system using intelligent algorithms and techniques. This involves utilizing artificial intelligence, machine learning, and other computational methods to optimize the functioning of complex systems.

II. Intelligence Control For Complex Systems

There are several key components of intelligence control for complex systems:

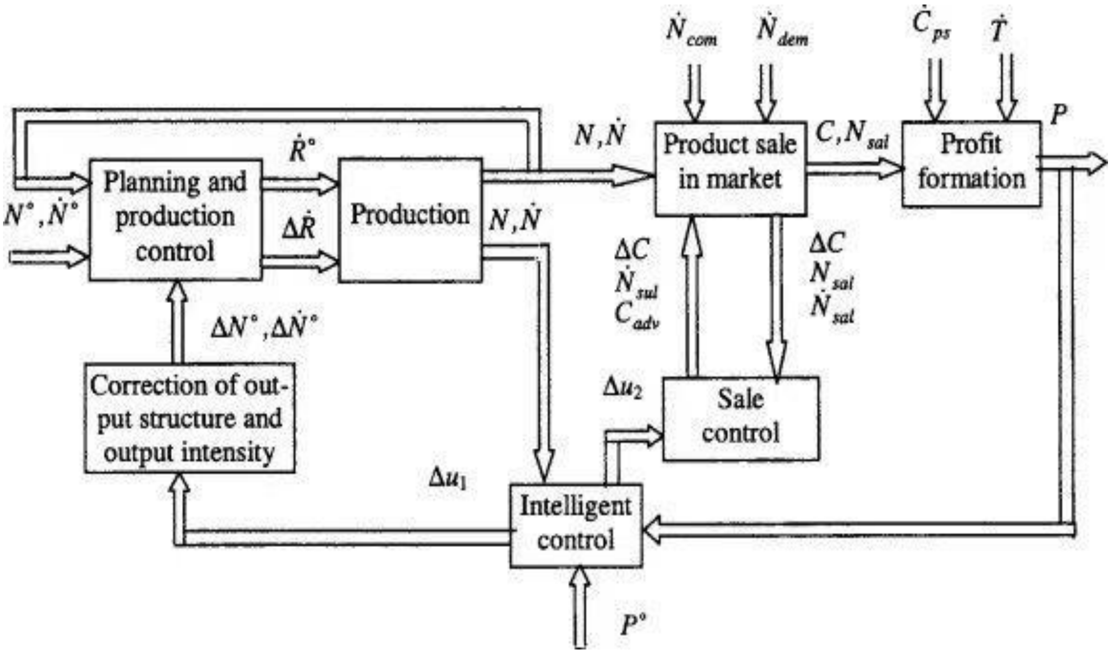

Fig 2: Intelligent Control

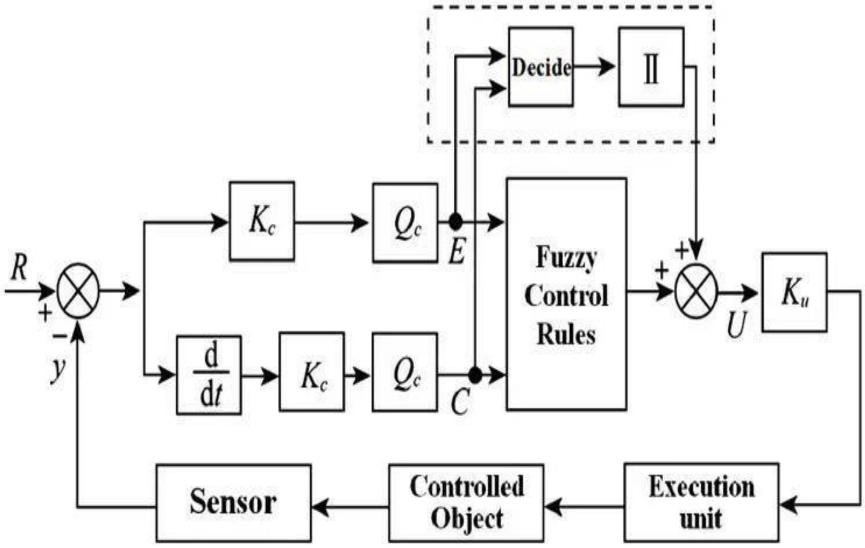

Fig 3: Fuzzy Control System

1. Modeling and simulation: Creating accurate and detailed models of the complex system is essential to understand its behavior and dynamics. These models can then be used to simulate different scenarios and assess the impact of various control strategies.

2. Sensing and data acquisition: Gathering real-time data and information from the complex system is crucial for intelligence control. This can involve using sensors, IoT devices, and other data collection methods to obtain information about the system's state, performance, and environment.

3. Data preprocessing and analysis: Raw data collected from the complex system needs to be preprocessed and analyzed to extract meaningful insights. This involves techniques such as data cleaning, feature extraction, and statistical analysis to transform raw data into relevant information.

4. Decision-making and control algorithms: Intelligent control algorithms are developed to make decisions based on the analyzed data and system models. These algorithms can range from simple rule-based systems to sophisticated machine learning algorithms that adapt and optimize control strategies over time.

5. Feedback and adaptation: Complex systems often exhibit dynamic and evolving behavior, requiring adaptive control strategies. Feedback mechanisms are incorporated into the control algorithms to continuously monitor the system's performance and make necessary adjustments in real-time.

6. Human-machine interaction: While the intelligence control algorithms automate many tasks, the involvement of human operators is still critical. Effective human-machine interaction interfaces are developed to facilitate collaboration and decision-making between humans and intelligent control systems.

7. Performance monitoring and optimization: Monitoring the performance of the complex system and the effectiveness of the intelligence control is essential. Performance metrics and optimization techniques are used to evaluate the control strategies and identify areas for improvement.

Intelligence control for complex systems is applicable in various domains, such as manufacturing, transportation, energy, healthcare, and finance. It can help improve efficiency, safety, reliability, and overall performance of these complex systems.

General control system intellectualization issues

The efficacy of control systems and technologies being developed is critical to the successful resolution of problems to ensure the state's technological independence in the sphere of civil and military purpose complex technical object creation and application. There is adequate theory and control technology. Taking into consideration the possibility of a lack of specific (depending on the application) required resources: information, timing, energy, money, material, human, and so on. Accidents and disasters in transportation, industry, and energy are frequently related with the so-called "human factor" (HF), including operator overwork. HF frequently happens as a result of quality issues in control system design, particularly in controllability emergencies. Human errors, as well as the exhaustion of technical resources of objects and control systems, are all too typical in today's Russian environment. They urgently demand guaranteed control dependability and quality, as well as updates to project, operational, and

modernization control capacities. Under the following conditions, methodologies and technologies for evaluating control systems and ensuring their optimality, functional and operational dependability, efficiency, fault tolerance, and survival are required:

- a lack of prior knowledge about the control object and its external environment of operation, even in opposition conditions;
- a large number of stationarity elements that are difficult to account for due to their subjective nature;
- Degeneration (due to failures or accidents) or the requirement for focused reconfiguration (revitalizing or developmental control).

Control systems get significantly more difficult as functional burden increases. Among the complexity factors of modern and advanced control systems are:

- multilevel controls, heterogeneity in subsystem description by quantitative and qualitative models, different scales of processes in space and time, multimodality, multilink, decentralization, ramified nature, and general structural complexity of modern control systems and their control objects,
- presence of uncontrolled coordinate-parametrical, structural, regular, and singular impacts, including active counteraction in a conflict environment,
- Use of the non-linearity, dispersed parameters, delay in control or object dynamics, impulsive impacts, high model size, and other factors.

Adaptive, robust, predictive, and other control approaches established in control theory are meant to account for dynamics' incompleteness by receiving missing information during the training stage or in real time. The use of AI involves extending the capability of complicated control systems by addressing tasks that are unknown or quantifiable. Models that are no longer valid as of some point in time, as well as tasks where quantitative models are less efficient than using AI models (such as in action planning tasks) or can be used in conjunction with AI models [1]. For action planning tasks and control in general, a range of artificial intelligence approaches neuronal, evolutionary, logical, and others - can be applied.

Adaptive, robust, predictive, and other control approaches established in control theory are meant to take into account. Each of these classes has advantages and limitations, particularly in terms of real-time requirements, and ensures the implementation of higher levels of heterogeneous control over complex systems. The intensive development of technical systems and technological processes (networking, miniaturization of sensors, controlling devices, and calculators, improving their performance, and so on) places new demands on modern control systems and opens up new opportunities, both at the level of embedded control systems of various scales and at the level of group interaction of decentralized multi-agent systems. The shift from robots operating in an unpredictable environment yet equipped with an operator interface. Current research and development is focused on the transition from robots operating in an unpredictable environment but equipped with an operator interface (supervisory UAVs) to intelligent robots. At that point, less expensive robots based on a modular concept of construction and miniaturization are required to solve sensitizing, environment modeling, robot control team goals, and application scope extension difficulties. Even in agricultural and road construction, drastic standards transformation demands robots with high-precision navigation and cognitive control.

Large-scale infrastructure systems in the electric power industry are examples of critically essential technological processes and intellectual control objects. In this situation,

- an inefficient structure of electrical grids and producing capacity,
- a lack of energy savings in electricity usage,
- technological and commercial losses in electric networks,
- technological lag and excessive equipment wear,
- a high level of monopolization in power markets,
- Vulnerability of electric power networks to terrorist and cyber attacks,

And other factors necessitate the development of models of complex infrastructure dynamic systems and the development of efficient solutions and highly dependable intelligent control systems for smart grids [4-6].

Control based oenological-reactive (production) knowledge model in the so-called expert, recommender or systems that help decision-making that need to be improved with new features:

- collaborating with other intellectualization techniques for control systems (artificial neural networks, genetic algorithms, and adaptive, resilient, and predictive control algorithms),
- By combining methods of symbolic and multimedia presentation and knowledge processing,

- operating with partially formalized and natural language texts, abdicative and inductive knowledge updating,
- Integrating quantitative and qualitative models with ontologies of various subject domains that characterize the problem situation, logical control systems' interface complexity with the outside physical world can be reduced.

There are numerous methods to combine various AI techniques. For instance, the 1-st order logical techniques of intellectual control from [1,7] can be linked with the neuro-reactive and logical-reactive (productional) AI means. While the first two strategies promote "reasonable" conduct, the latter methods can address a wider range of information. Based on giving the control system's simplest heuristic responses for changes to the environment or the controlled object. Verification of knowledge presentation is especially important at the logical-reactive level (sometimes with its many "if-then" rules). The verification of a knowledge base can be reduced to the dynamic analysis of automata networks in the case of production rules of the Boolean type and constructive semantics. This analysis is further condensed in the class of monotonous automata with respect to the state the state by application of method of mathematical model's properties transfer [8].

The important problem in AI is the problem of automatic estimation of irrelevance of knowledge, because not only a deficit but also a surplus of information causes degradation of intellectual control systems. Recent advances in the field of intellectual control include the automation of searching for ways to achieve the control goal given externally, while the automation of goal-setting and revision of control quality criteria is not sufficient yet. It is now also recognized that improvement of only "machine components" in developed human machine systems is not enough for the desired essential increase of their use the efficiency . This goal in creating anthropocentric systems can be achieved by directing the efforts of engineers and scientists on improving the intellectual component of the "system-core" in anthropocentric system as built-in set of algorithms for embedded computers together with algorithms of operator activity, referred to as "on-board intelligence" [8,9]. First and foremost the on-board intelligence is required in aviation, especially in combat situations, typical for fighters, i.e. in the circumstances of the most aggressive external environment and tight timing constraints for the crew. On-board intelligence is a functionally integral complex, aimed at the fulfillment of all aircraft tasks [9]. Scientific and technological advances in this field will be useful also in other applications of AI in the conditions of a multicriticality, uncertainty and risk to improve control quality in a situation of information overloading the operator, limited time or stress. Development of practically useful on-board decision-making support expert systems, including those based on fuzzy logic and case-based reasoning by analogy, has reached the practical stage of building the models and prototypes. They are intensively developed in the world in favor of the creation of the manned combat aircraft of the 4++ and 5th generations, as well as combat UAVs. Their fragments already appear on the modernized fighters of 4++ generation. In foreign developments, they are planned to be used ,first of all, on board of the new USA fighters F-22, F-35, modernized F-16, F-15, F/A-18 and helicopters, which have a number of on-board intellectual systems of tactical decision making [9].The results of the research, the improvement of on-board computers, cockpit displays and controls as well as other avionics give the constructors of next generation aircraft / helicopter an opportunity to design and realize a-board computer systems of a new type. These systems will be capable to support tactical decisions making (the prompt appointment of the current purpose of flight and choice of a rational way of achieving the goal). Solving such tasks on past generations aircraft could be only completed by the efforts of the crew. Further we consider in details some questions of intellectualization of automatic control systems in the form of fuzzy regulators and combining them with other AI means. Note that the first regulators developed in Greece in the 3rd century BC partly can be considered as the fuzzy controllers described linguistically with logical operations. Today, a huge number of practical applications of fuzzy control systems in the industry, transport, energy, oil and gas, metallurgy, medicine and other industries and household appliances can be observed in Japan, China, USA Germany, France, Britain, Russia and other countries. We consider four basic types of regulators: logical-linguistic, analytical, learned and proportional-integral differential (PID) fuzzy controllers [1, 7, 11-17]. Since the information about them is not systematized and is scattered in many publications, our analysis will help a specialist to orient himself in this field.

III. CONCLUSION

intelligence control for complex systems involves employing advanced algorithms and techniques, including artificial intelligence and machine learning, to effectively manage and manipulate complex systems. The key components of intelligence control include modeling and simulation, data acquisition and preprocessing, decision-making and control algorithms, feedback and adaptation, human-machine interaction, and performance monitoring and optimization. By using intelligence control, we can better understand the behavior of complex systems, make

informed decisions based on real-time data and system models, and adapt control strategies in real-time. This can lead to improved efficiency, safety, reliability, and overall performance of complex systems in various domains.

Intelligence control is a vital area of research and development as we continue to face increasingly complex systems in our modern world. With advancements in technology and the availability of large amounts of data, intelligent algorithms have the potential to greatly enhance the management and control of these complex systems, leading to better outcomes and more efficient operations.

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